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Accurate three dimensional characterization of ultrasonic sound fields (by computer controlled rotational scanning)

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ACCURATE THREE DIMENSIONAL CHARACTERIZATION OF ULTRASONIC SOUND FIELDS (BY COMPUTER CONTROLLED ROTATIONAL SCANNING)

Paper accepted for presentation on 14 September 1981 at the "Second European Conference on Non-Destructive Testing", to be held in Vienna.

H.E. Gundtoft and T. Nielsen

Abstract. A rotational scanning system has recently been developed at Risø National Laboratory. It allows sound fields from ultrasonic transducers to be examined in 3 dimensions. Using different calculation and plotting programs, any section in the sound field can be plotted. Results from examination of transducers for automatic inspection are presented.

INIS descriptors: AUTOMATION; INSPECTION; MEASURING METHODS; TRANSDUCERS; TUBES; ULTRASONIC TESTING.

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Accurate Three Dimensional Characterization of Ultrasonic Sound Fields (By Computer Controlled Rotational Scanning).

Caractérisation tridimensionnelle exacte des champs ultra-soniques (par balayage rotatoire côntrole par un ordinateur).

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Schallfelder von Ultraschall-Prüfköpien können in unserem neuentwickelten Rotationsscannersystem in drei Dimensionen untersucht werden. Mit Hilfe von verschiedenen Berechnungs- und Kurvenschreiber-Programmen kann jeder Querschnitt in dem Schallfeld aufgezeichnet werden. Ergebnisse der Prüfung von Prüfköpfen für automatische Kontrolle werden vorgelegt.

Sound fields from ultrasonic transducers can be examined in 3 dimensions, in our recently developed rotational scanning system. Using different calculation and plotting programs, any section in the sound field can be plotted. Results from examination of transducers for automatic inspection are presented.

Les champs soniques de palpeurs ultra-soniques peuvent être étudé à trois dimensions à l'aide de notre système de balayage rotatoire récemment développé. Par utilisation de différents programmes de calcul et de répresentation, chaque section du champ sonique peut être représentée. Les résultats d'études de palpeurs pour l'inspection automatique sont présentes.

INTRODUCTION

It is a well known fact that in ultrasonic inspection it is very difficult to get the same results from one laboratory to another.

Several round robbin tests have had this conclusion. Even with the same procedures, it is difficult to reproduce the results.

The problem is partly due to the fact that ultrasonic transducers with the same specification, are different.

Sound field examination in water is one of the methods which can be used to characterize the transducers.

We have, in particular, been working with focussed transducers used in automatic inspection systems. Here sound field examination is of importance, to certify that transducers of the same specification have identical sound fields. This paper deals with the procedure and the results that we have obtained for ultrasonic transducers (used in tube inspection) in our newly developed three-dimensional sound field examination equipment.

The system is now also being used on other transducers, and furthermore we are trying to replace the ball reflector in the system with a minihydrophone, so that we can separate the transmitted signal from the reflected signal.

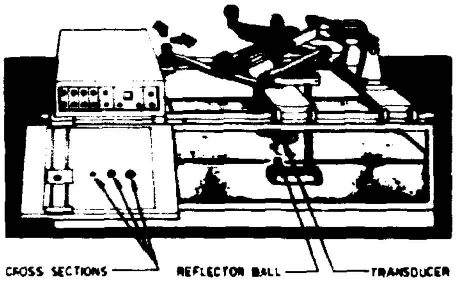
SOUND FIELD EXAMINATION

Normally a laboratory ultrasonic scanning system is used for sound field recording. However, this system will only make a recording of the sound field at a scale 1:1 directly during examination.

A ball reflector is moved relative to the transducer in two directions (x-y) and the resulting echo is recorded as different grey tones determined by dB value at echo peak maximum.

This method is far from accurate enough to give useful results from small diameter focussed transducers.

We have improved the normal laboratory scanning system to incorporate a pantograph between the ball and the recorder. This enables a mechanical enlargement of up to 7 times (Fig. 1 & 2).



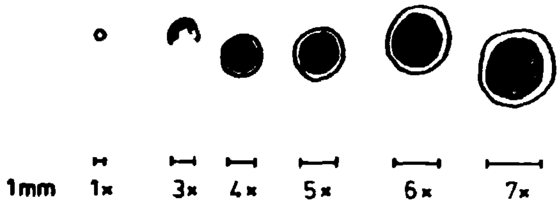


Fig. 1. Pantograph Measurement   Fig. 2. Mechanical Enlarged Sound Fields.

With this system examination can be carried out reproducibly when the transducer is not dismounted between tests. There are, however, several shortcomings as follows:

1) Enlargement too small.
2) Repositioning of the transducer is difficult or impossible.
3) The grey tones (dB levels) must be chosen before measurement is made.
4) Difficult or impossible to correlate the geometry of the transducer housing with the sound field geometry.
5) Impossible to make sections in a "vertical" (z) direction.

Several computer controlled ultrasonic scanning systems are now on the market and thus it should be possible to store information about the reflected echo height from the ball together with the position of the ball. In Ref., a method is mentioned where a cross-section of the field is measured and stored in the computer. The ball reflector is moved in two directions (x-y) by stepper motors. The movement in the z-direction is not computer-controlled.

OUR ROTATIONAL SOUND FIELD EXAMINATION SYSTEM

To get a complete picture of the sound field from a transducer, the ball reflector must be positioned everywhere in the whole sound field which shall be inspected. A reasonable resolution in measurement demands that the steps in ball position be small.

This can be achieved by moving the ball and the reflector relative to each other in three directions (x-y-z) by stepper motors.

Instead of this we have made our rotational scanning system where the transducer rotates around its own axis, and also can be moved along this axis. The ball reflector is moved perpendicular to this axis (Fig. 3).

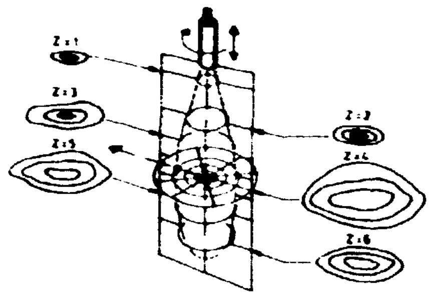


Fig 3. 3 Dimensional Scanning.

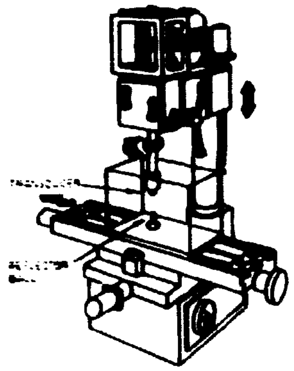


Fig. 4. Practical Arrangement.

Rotational scanning has several advantages:

1) We have a smooth (rotating) movement with no mechanical play from stepper motors moving a cross table forwards and backwards.
2) The system can show the difference between the geometrical axis of the transducer housing and the acoustical axis of the sound field.
3) With the same pulse repetition frequency we have a dilution of the measuring points when the ball reflector is moved away from the center axis.
4) The echo height varies only sligthly from one measurement to the next.

In Fig. 4 is shown how our rotation scanning system is built. We have built it around a small milling machine. The transducer is placed in the tool position and rotates at 120 revolutions per minute. By means of a signal transmitter the signals are taken to and from the rotating ultrasonic transducer. The cross table on the mill gives a possibility for movement in both x- and y-directions. During measurement of the sound field the ball is only moved in the x-direction by a stepper motor. Movement in the z-direction in the sound field is made by lowering the transducer with the milling machine's vertical movement, using a stepper motor.

Synchronization and triggering of the ultrasonic apparatus and the computer is controlled from a disc with holes and photodioded on the top of the transducer fixture.

The disc has also a "zero" mark which ensures alignment between the different cross-sections. Hereby we assure an accurate and reproducible connection between the transducer and the reflector ball.

Before measurement the ball must be placed directly on the centerline of the rotation axis. Here we use the fact that the reflected echo height from the transducer is the same for the whole measuring circle when the ball is in the geometric centre of rotation.

By moving the ball in x- and y-directions with the two stepper motors we find the position of the ball corresponding to the smallest variation in echo height on the measuring circle. The ball is then placed in this position by moving it in the same direction in which the ball would later be moved during the actual sound field measurement. Thus we avoid the play between the stepper motor and the leading screw in the cross table. This whole alignment procedure is controlled by the computer.

OPERATING PROCEDURES

In our system the whole procedure has been divided into three parts:

A) Measurement and storage of the raw data (echo peak height and position).

B) Extracting and calculation on the values of interest for presentation.

C) Plotting these results.

The three parts are independent of each other and thus can be made at any convenient time. If only the raw data are stored, the calculation and plotting can be reproduced at any time. Furthermore, no original data are lost by data reduction and thus new calculations and plotting programs made in the future can also be used on old raw data. The complete system with scanning tank, computer and plotter is shown in Fig. 5.

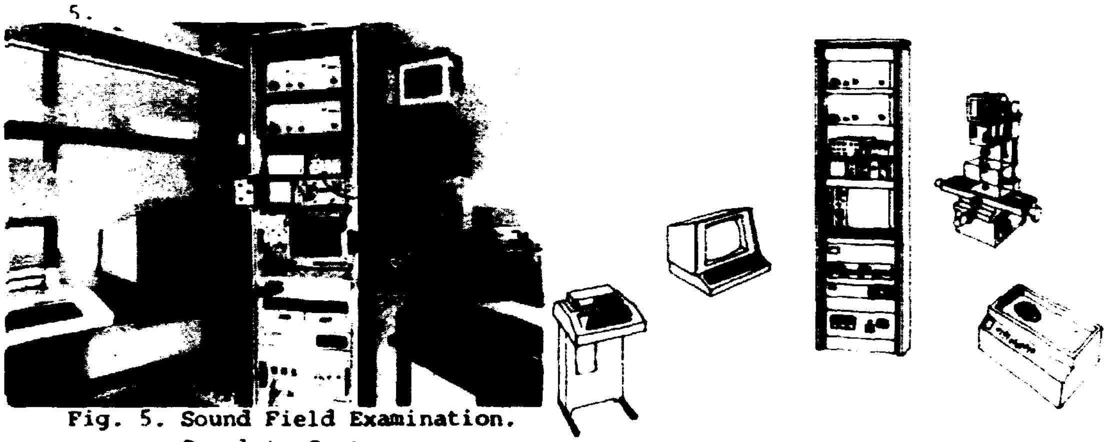


Fig. 5. Sound Field Examination. Complete System.

A) Measurement and storage of the raw data

The program asks for how many cross-sections should be made and the position of these cross-sections.

The computer must be told the distance between the transducer and the ball. This is read on the oscilloscope in µsec.

Furthermore the computer asks for how many measuring circles should be made and the distance between these circles.

A normal measurement cycle can comprise:
- up to 10 cross-sections,
- 400-800 steps (1.5-3 mm) between the sections,
- up to 20 measuring circles,
- 5-15 steps (0.0375-0.1125 mm) between the circles.

Measurements are made in 256 directions along the circles corresponding to the holes in the synchronization disc on top of the transducer. The number of measurements per circle is the only figure that is fixed. The above cycle will give up to 51200 single measurements which are stored together with the positions on the floppy disc.

The whole measuring cycle takes less than 5 min. with a rotational speed of 120 RPM.

B) Calculation

We have made three standard calculation programs. In all the programs we begin by finding the maximum measured value in each cross-section and also the maximum of all the measured echo heights. This is defined as "zero dB". All calculations are now made in dB with reference to this value. Thus the resulting plot is independent of the signal value used during the examination.

The raw measuring data are stored with their positions in polar co-ordinates, but the plotting data and their positions are calculated in linear (x-y) co-ordinates.

Cross-section (x-y PLOT) (Fig. 6)

The positions of the different isosonic lines in a cross-section at a certain distance from the transducer are plotted.

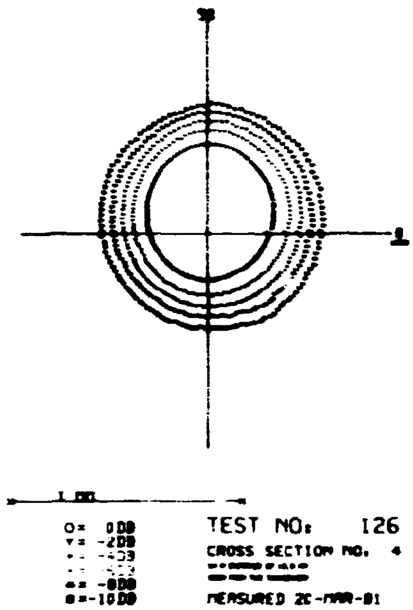


Fig. 6. x-y PLOT.

A separate marker type (and colour) is used for each dB level. In our standard presentation, we have chosen 0, -2, -4, -6, -8, and -10 dB as isosonic levels.

The computer asks if all cross sections shall be calculated.

The the enlargement (scale factor) shall be decided. Finally the calculation can be made referring to all the 256 measuring positions in the circle or to every second, third, fourth, fifth etc. point.

Directional plot (y-PLOT)

We have two different types of this plot:

- Radial direction (Fig. 7)

  This calculation gives the dB values in one (or more) diametrical direction(s) in the cross-section for one (or all) cross-section(s).

  The actual measured values along the measuring lines on the different measuring circles are plotted (converted to dB values). Only values down to -20 dB are plotted. In this program too, the enlargement for the plot shall be decided before the calculation.

- Non-radial direction (Fig. 8)

  Any non-radial direction can be calculated and presented in a similar way. Thus we are not limited by the original polar co-ordinates used in the rotational scanning of the sound field.

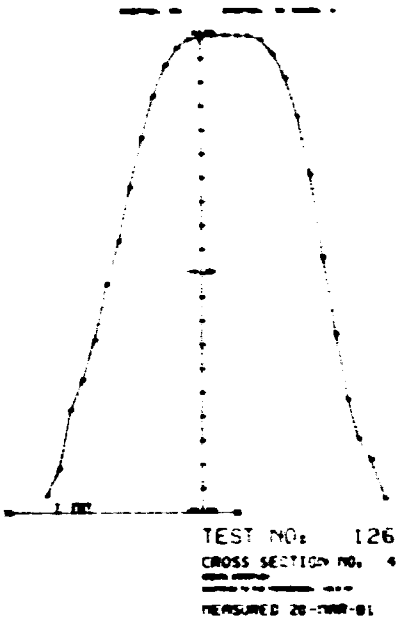


Fig. 7. Radial y-PLOT.

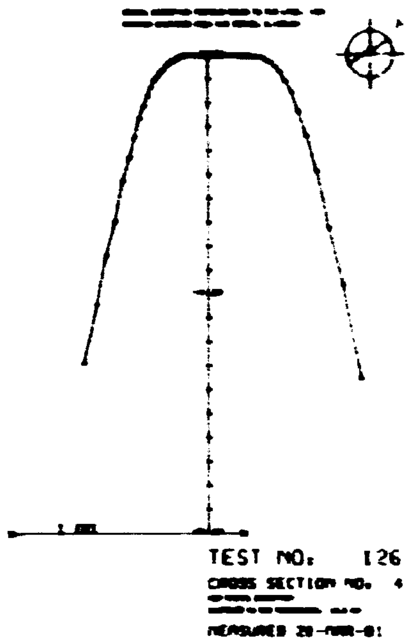


Fig. 8. Non-radial y-PLOT.

Longitudinal section (z-PLOT)

The longitudinal section takes values from the different cross-sections and combines these in a z-plot. Here again we use the isosonic lines and in our standard presentation we also use 0, -2, -4, -6, -8, and -10 dB, with different marker types and colours.

- Radial longitudinal section (Fig. 9)

One (or several) diametrical direction(s) can be chosen and the computer calculates the position of the dB isosonic lines down to -10 dB.

The enlargement must be decided.

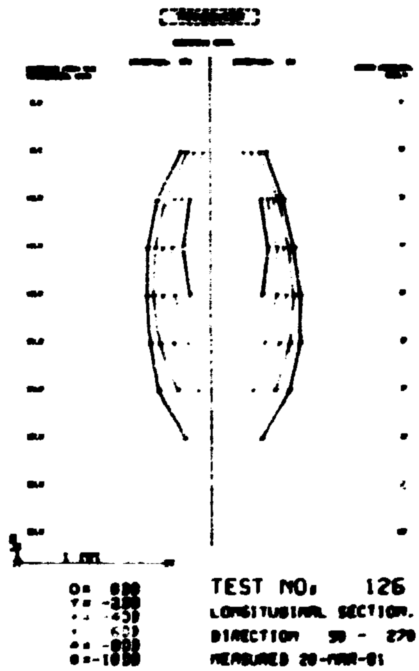


Fig. 9.
Radial z-PLOT

- Non-radial longitudinal section (Fig. 10)
As for direction plot, any non-radial direction can be chosen for a longitudinal section.

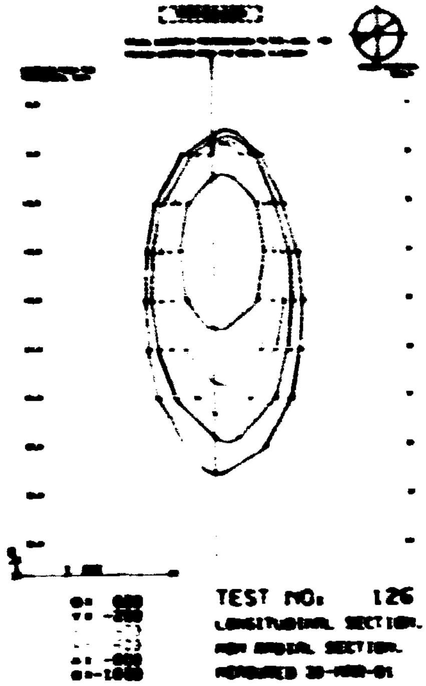


Fig. 10. Non-radial z-PLOT.

The calculation time varies but for the above examples, the first part of the calculation to find the max-values (zero dB) takes about 50 secs., if the test has comprised all 51200 measurements. The x-y cross-section takes about another 4 mins. for all 10 cross-sections; for y-plot and z-plot, the calculation takes another ½-2 mins. depending on the number of directions that are demanded. The non-radial sections take a little more time.

C) Plotting

Plotting of the calculated results is made on a computerized plotter with up to 8 different colours. We use up to 5 different pens because we have 5 different marker types. Thus it is possible to have black and white copies without loosing information.

Plotting of the "picture" takes up to 10 mins. depending on the number of values to be plotted in the specific picture.

Both in the calculation and in the plotting sequence, part of the time is used to make the text on the resulting picture.

The whole procedure with measurement-calculation and plotting can be made in less than ½ hour for a single picture and this time can easily be reduced if a graphical monitor is used instead of the plotter.

RESULTS

With this system we have examined the following transducers, which have all been used in tube inspection:

FREQUENCY (MHz)	DIAMETER OF THE CRYSTAL (mm)	FOCUS (mm)	ITEMS	USED FOR:
22	3.2	25.4	5	Diamentional measurement
25	6.4	19.0	5	
5	6.4	19.0	2	Defect inspection

This examination has revealed differences between transducers of the same type. As an example the results from three of the 22 MHz transducers are shown in Figs. 11 and 12. (Cross-sections and longitudinal section for transducer I, II and III).

We can see that the focalpoint is not at the specified distance from the transducer. Furthermore, there are individual differences between the transducers.

The alignment between the transducer housing and the crystal is not perfect.

The two remaining transducers in this group were so damaged that the signal to noise ratio was unacceptable.

For the five -25 MHz - transducers we found a much better agreement between the specified and the actual measured focalpoint, but also here we have individual differences between the transducers, especially with regard to the alignment between the transducer housing and the crystal. The best agreement between the measurements and the specification has been found for the two -5 MHz-transducers.

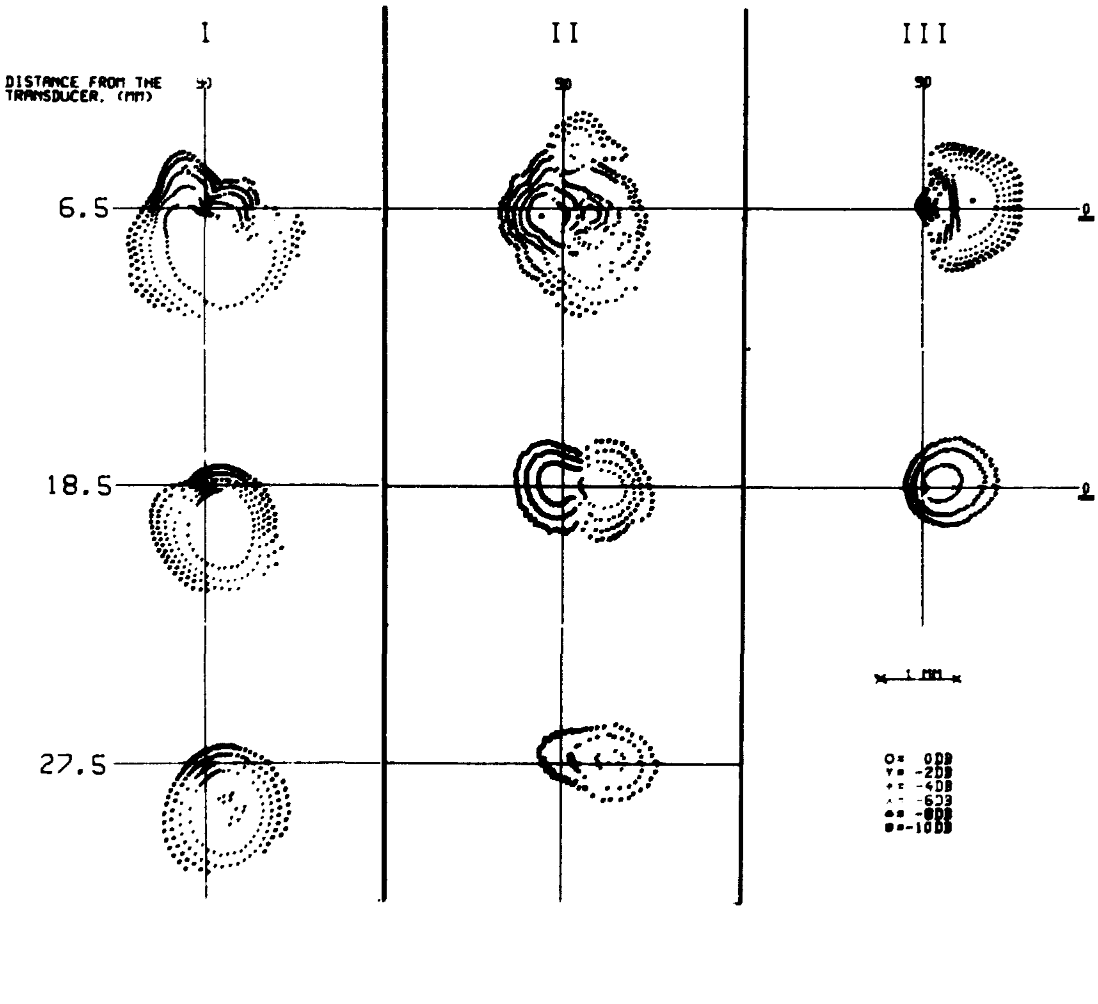


Fig. 11. Cross Sections From 3 Transducers.

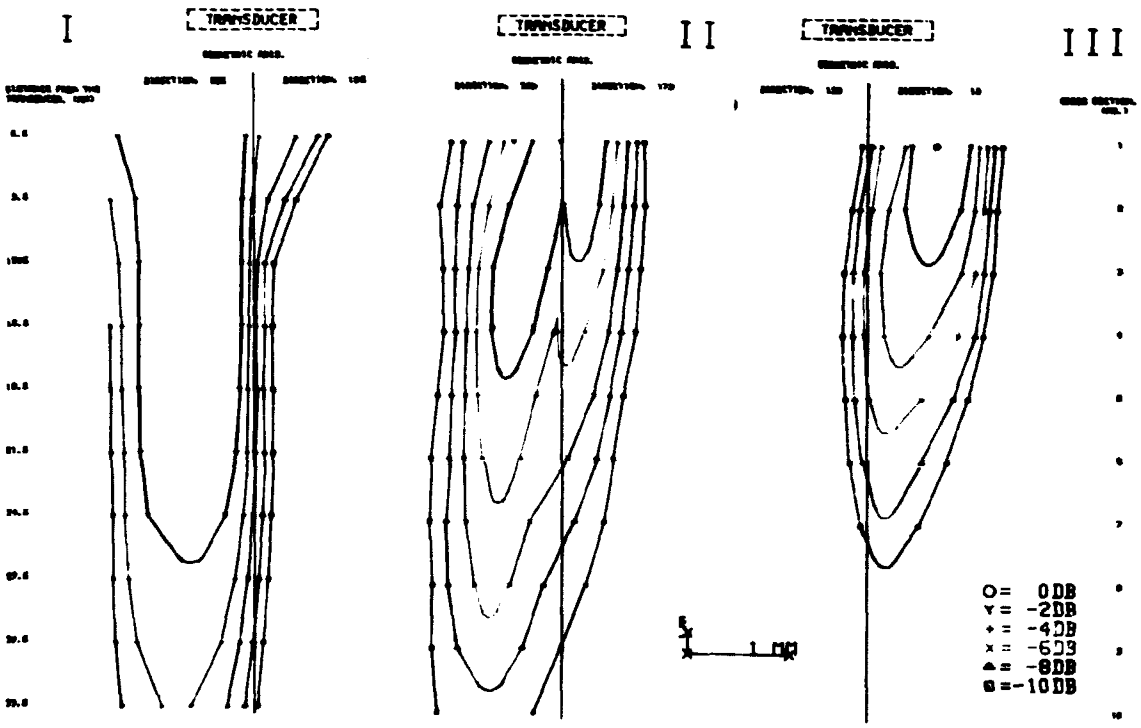


Fig. 12. Longitudinal Sections From 3 Transducers.

FUTURE DEVELOPMENT

Instead of measuring and recording the height of the reflected echo from the ball, we will now place a mini-hydrophone where the reflector ball is. In this way we will be able to measure the transmitted signal and thus see a possible difference between transmitted and reflected signals. Hereby the qualities of the transducers transmitting and receiving capabilities can be examined independantly.

CONCLUSIONS

With our rotational sound field examination system, accurate and fast inspection of sound fields in water is made possible.

The raw inspection data can be stored for later evaluation and comparison with new results from the same transducer, after it has been in use for some time. With all the raw data stored on the floppy disc and with a reliable and precise system, the change of the sound field with time during use of the transducer can be followed.

The system can also be used in the evaluation of new transducers to judge whether they are in accordance with the specification for sound field focusing. The shape and geometry of the sound field is determined with high accuracy.

The system has mainly been used for examination of focussed transducers for tube inspection, but we are now also exploring the possibility of using the system for examination of other transducers.

ACKNOWLEDGEMENTS

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